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The New Innovators:

Global Patenting Trends in Five Sectors

THE NEW INNOVATORS:

GLOBAL PATENTING TRENDS IN FIVE SECTORS

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FOREWORD

At the end of World War II, the United States accounted for more than 40 percent of the world's gross domestic product and was its undisputed industrial and technological leader. In the decades that followed, the United States invested trillions of dollars in research and procurement, driven in large measure by national security and health missions. These investments constantly pushed back the frontiers of technology, building whole new industries and sustaining U.S. preeminence. The size and sophistication of U.S. markets, a superb technological infrastructure, and a willingness to embrace the new over the old made the United States the launch market of choice for new technologies and products, conferring on it a decisive economic advantage.

The emergence of a dynamic global economy and the globalization of the factors that drive economic growth may be altering that advantage. Some of the highest growth rates in demand are not at home but overseas, where four billion consumers have entered the global marketplace since the mid-1980s. Companies are meeting global demand by managing innovation on a worldwide basis. Countries around the world are ramping up their capabilities for innovation with breathtaking speed and determination. Advances in information technology have made knowledge quickly accessible even in remote corners of the world.

The creation and application of knowledge have now become truly globalized. The international diffusion of research and development and production; proactive efforts by many governments to attract high value-added direct investment; attempts by some governments to obtain intellectual property in return for market access; and concerted foreign investment in research, technology, and human capital may create new and formidable international competitors. Thus, the challenge for the United States in the next century could come not from low-cost producers but from low-cost innovators.

This analysis is intended to aid the understanding of the critical role that science and technology play in ensuring the economic competitiveness of the United States. A strong, sustained commitment to investment in science and technology, the means to rapidly integrate new knowledge and technologies into products, and access to growing global sources of innovation will enable the United States to continue to push back the frontiers of technology, build new industries, and create high-wage jobs for Americans.

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Executive Summary

This report analyzes the competitiveness of the research enterprises of the United States, the European Union (EU) as a group, and 14 other countries.[1] This analysis uses key indicators generated from utility invention patents granted under the U.S. patent system, which is generally considered to be the best level playing field for quantitative, international technological comparisons.

These indicators show that the United States has a clear technological edge in each of the sectors examined—health, advanced materials, automotive, information technology, and express package transportation and logistics (EPTL)—and is not likely to relinquish this leadership to any nation in the near term. Given the strong documented linkage between the strenators bode well for the future of the American economy.

Nevertheless, our analysis reveals quickening technology cycle times (TCTs) and greater linkages to leading-edge research—trends that may enable countries to leapfrog generations of technologies within a brief span of time. The process of transitioning from imitator to innovator has been dramatically compressed. For example, over the past decade, the Republic of Korea (Korea) and Taiwan have overtaken the United Kingdom (U.K.) and Germany in the number of information technology patents granted in the United States. Ireland, Israel, and India also are emerging as global players in information technology, according to the patent data.

General Findings/Trends

The data presented in this study lead to some key findings for policymakers to consider as they develop strategies and activities to maintain and reinforce the U.S. capacity for innovation. These findings include the following:

- A capacity for world-class research appears to be increasingly important to the innovation process around the world.

[1] The 15 EU member states are Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden, and the United Kingdom.

- The United States may be at a competitive disadvantage due to its relatively slower cycle times in some critical technologies. The generation of new knowledge must be combined with its rapid deployment to create economic benefits from innovation.

- The United States has the strongest overall research capabilities in the world and is not likely to relinquish this position to any country in the near term. However, over the long term, this position will be challenged by small and large countries alike.

These findings indicate that the globalization of research capacity, a high rate of technology churn, and shorter learning curves mean that past leadership is no guarantee of future leadership.

Significant Overall Findings/Trends

- The United States ranks first in all the sectors, while Japan ranks second except in health, where the EU ranks second. The U.S. margin of leadership is widest in the health sector and narrowest in the advanced materials and automotive sectors. The U.S. technological lead appears to be widening in the automotive, information technology, health, and EPTL sectors. The trend in advanced materials is somewhat less certain.

- Of the approximately 110,000 utility invention patents granted in the United States in 1996, inventors in the United States received about 61,000 (55 percent).

  Japan places a distant second to the United States but leads all other nations by a wide margin with about 23,000 patents (21 percent). The EU as a whole had about 16,400 (15 percent), with Germany accounting for about 6,800 (6 percent) and the U.K. about 2,400 (2 percent). Behind the U.K. were Taiwan with about 2,000 and Korea with about 1,500.

  Other countries in the study received much smaller numbers of U.S. patents, ranging from about 500 each for Australia and Israel to 12 for Malaysia. However, the number of U.S. patents granted annually to each of these countries is rising; the rate of increase is highest for China and Singapore.

Table 1. U.S. Patents by Sector, 1982 and 1996

Sector	Approx. Number of Utility Patents/Year 1982	Approx. Number of Utility Patents/Year 1996	Percentage Growth
Advanced Materials	250	1,200	+333
Information Technology	4,000	16,000	+305
Health	2,000	4,700	+189
EPTL	600	1,500	+151
Automotive	1,300	2,700	+105
All U.S. patents	58,000	110,000	+89

Note: EPTL = express package transportation and logistics

- Taiwan and Korea have the fastest growth rates in the number of patents granted per year. If current growth rates continue, both Taiwan and Korea will soon pass the U.K. in the number of U.S. utility patents they receive.

- Information technology is by far the largest of the five sectors, with more than three times the number of patents of the second largest sector, health (see Table 1). Health, in turn, has almost twice as many patents as the next largest sector, automotive. And the automotive sector accounts for about twice as many patents as each of the remaining two sectors.

- In each of the five sectors, the patent growth rate between 1982 and 1996 was significantly greater than for the U.S. patent system as a whole.

- Nations' strengths differ by technology:

  - Japan is strongest in information technology.

  - The U.K. is a major player only in health.

  - Israel is strong in health but weak in automotive.

  - Taiwan is strong in automotive but weak in health.

- Some smaller countries have “high-impact” patents:
    - Israel and Ireland have high-impact U.S. patents in the health sector.
    - Taiwan, Korea, and Israel have high-impact U.S. patents in information technology.
- The characteristic difference between U.S.-invented and Japanese-invented patents in all the sectors is that Japanese-invented patents tend to have faster TCTs and U.S.-invented patents tend to have significantly higher linkages to science.

Significant Findings/Trends by Key Indicator

Patenting Activity

- The patenting rate of many developing and emerging nations has increased dramatically in recent years. This is particularly true for Korea—which had 30 times more patents in the decade between 1986 and 1996 than in the previous decade—and for Taiwan, which saw a tenfold increase during the same period. If the current patent growth rates hold, within a few years both Taiwan and Korea will surpass the U.K. in the number of U.S. patents granted annually.
- China and Singapore show the fastest growth in U.S. patents, though the number of patents granted to each is still small. Comparing the number of patents granted in the five-year period 1992 to 1996 with the number granted in the five-year period 1987 to 1991, China’s patents grew seventeen-fold and Singapore’s grew ninefold. Brazil, India, Israel, and Ireland more than doubled their patents over 1992 to 1996. Significantly, these nations are becoming increasingly strong performers in the sectors analyzed in this report.

Technology Strength

- The combination of high numbers of patents and high citation rates on those patents makes the United States the undisputed leader in this indicator of technology strength.
- The U.S. margin is widest in the health sector and narrowest in advanced materials.

- In automotive-related patents, the United States has recaptured the lead Japan held in the early 1990s. Even in information technology, the gap between the United States and Japan, while not very wide, is increasing. Israel, Australia, and Ireland have some high-impact patents in the health sector. Taiwan has high-impact patents in the automotive sector. Korea, Taiwan, and Israel have some high-impact patents in information technology.

Non-Patent Reference (NPR) Score (Science Linkage)

- In general, the linkage between leading-edge science and technology, as embodied in patents, is growing most noticeably in health. Of the five sectors studied, health and advanced materials have the highest linkage to basic research.

- Innovation in information technologies, EPTL, and the automotive sector is considerably less dependent on science.

- Patents of inventors residing in the United States show the greatest linkage to science in all sectors. Other countries' patents, however, reflect a growing science linkage: Japanese patents in advanced materials; U.K. patents in the automotive and information technology sectors; and Australian patents in the health sector.

Technology Cycle Time

- U.S. TCTs are slower than other nations' in almost every sector—by about 10 to 50 percent, depending on the sector—especially in comparison with Japan's.

- Japan has the fastest cycle time in each sector, but other countries are pacing the Japanese rate of technology turnover in certain sectors. In advanced materials, Germany and the U.K. have made rapid progress in shortening cycle times. In the automotive sector, Taiwan has cut its cycle time in half, while the U.K. is on par with Japan.

- Both Taiwan and Korea have overtaken Japan in TCTs in the information technology sector, emphasizing fast commercialization with less dependence on basic or leading-edge science.

- The time between succeeding generations of technology is getting shorter as measured by TCT, in all sectors except for health.

- In the health sector, TCTs have increased, not decreased. However, in this increasingly science-based sector, the links between new developments and older technology (patented prior art) are relatively less important than links to current scientific research.

INTRODUCTION

Overview

CHI Research, Inc., the U.S. Department of Commerce's Office of Technology Policy, and the Council on Competitiveness examined the patented technology of Australia, Brazil, China, Germany, Hong Kong, India, Ireland, Israel, Japan, Republic of Korea (Korea), Malaysia, Singapore, Taiwan, the United Kingdom (U.K.), the United States, and the European Union (EU) as a whole, in five technology sectors—health, advanced materials, automotive, information technology, and express package transportation and logistics (EPTL)—to assess the competitiveness of the U.S. research enterprise and gain insights into the technology strengths and directions of other nations.

Methodology

Data Source/Indicators

For this analysis, we examined U.S. utility invention patents granted between 1982 and 1996 and assigned these patents to our five sectors, if they met the criteria discussed below. Information gleaned from these patents was then used to compute several standard indicators—patenting activity, current impact index (CII), activity index (AI), technological strength (TS), non-patent reference (NPR) score, and technology cycle time (TCT)—for each year and for each country, as well as for each of the three five-year periods.

The definition and meaning of each of these indicators are presented in Box 1. A more detailed explanation of each indicator is provided later in the report.

Assignment of Patents to Countries

Patents were assigned to a country based on the first-given inventor's home address, rather than the corporate home office address of the assignee. This method assumes that inventors are likely to live in the country where the work was done. This approach allowed us to develop a more accurate indicator of each country's indigenous technological strength.

Box 1. Technology Indicators

Patenting Activity—the raw number of a nation's patents; patenting activity in the U.S. patent system—overall and by sector—provides a rough measure of inventive activity. There is a strong positive correlation between the patenting activity of a nation in the U.S. system and its gross domestic product (GDP)—the higher a country's GDP, the more it patents. Many experts consider patenting activity to be the best proxy measure available for innovative capacity. Patents filed internationally tend to be more significant than those filed in the home country alone.

Current Impact Index (CII)—a normalized indicator of the number of times a group of patents is cited in another patent; measures the extent to which current technology is building on a group of patents; provides an indicator of the quality of a country's patent portfolio in a particular sector.

Activity Index (AI)—the percentage of a country's U.S. patents in a sector, divided by the percentage of all U.S. patents in that sector; measures a country's relative technological emphasis.

Technological Strength (TS)—a combination of the raw number and quality (as measured by the frequency of citations in later patents) of a country's patents; reflects the quality-weighted strength of a country's patent portfolio.

Non-Patent Reference (NPR) Score—the number of non-patent prior-art citations in patents. The higher the NPR, the closer the linkage to leading-edge science.

Technology Cycle Time (TCT)—the median age in years of prior patents cited; provides an indicator of the pace of technological change.

Assignment of Patents to Technology Sectors

In the **health sector**, we used patents related to drugs, medicines, and biotechnology, including genetically engineered drugs, immunological testing, and diagnostics. Medical devices and other healthcare-related patents were not included.

In the **advanced materials sector**, we used patents related to advanced ceramics, alloys (particularly lightweight alloys), composites, diamond thin films, membranes, biomaterials, high-temperature superconductors, and selected polymers. Although we found relatively few patents relating to these subjects, we also included as many patents as we could identify for advanced ways of making materials, namely combinatorial chemistry and molecular dynamics and materials modeling.

In the **automotive sector**, we used patents related to engines, transmissions, suspensions, brakes, steering wheels and tires, vehicle bodies and chassis, passenger accommodation and safety, pollution controls, and automotive manufacturing technology.

In the **information technology sector**, we used patents related to digital, optical, and analog computing hardware and software (including cryptography, voice and image recognition and processing, and data storage), and semiconductor manufacturing and applications patenting. Communications patents were not included.

The **EPTL sector** was difficult to define because the technologies that could be included in this category—such as vehicle and aircraft route management and position tracking—could also be placed in other sectors. For this analysis, we included in this sector patents related to non-bulk materials-handling technologies, such as conveyors, optical character recognition systems, and bar coding devices. Most patents granted to the leading companies in this sector (FedEx, UPS, U.S. Postal Service) are in materials handling and tracking.

Thus, we defined EPTL technology as a set of more generally applicable technologies, including data mining, which we narrowly construed to mean database and data management inventions related to materials handling. We excluded the very broad concepts of database management and data communications because of the overwhelming numbers of patents unrelated to the EPTL sector.

Patenting Activity Trends

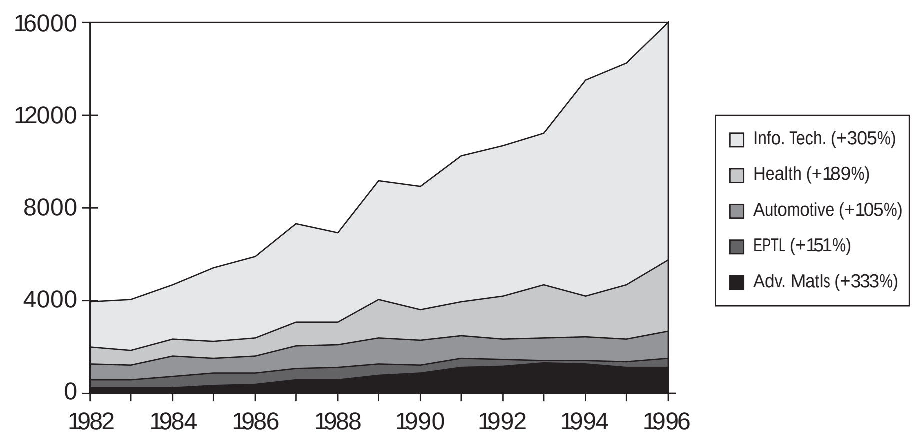
Patents are not the only way of protecting intellectual property rights. Copyright and trade secrets laws also protect certain types of intellectual property. For example, computer programs and integrated circuit configurations are usually protected by copyright. However, because patenting is the primary form of intellectual property protection, patent data are considered to be the most available, objective, and quantitative measure of innovative output.[2] Thus, a country's patenting activity is an indicator of the strength of its research enterprise and technological strengths, both overall and in particular fields of technology.

Patenting Activity by Sector

With the exception of the automotive sector, the patent growth rates of the sectors we examined significantly outpaced the overall patent growth rate in the U.S. patent system.

Figure 1. Sector Growth over the Past 15 Years (U.S. Patent Counts 1982–96)

(In same period, the U.S. patent system as a whole grew 89 percent)



Note: sector patent counts = all U.S. patents in sector; growth = percent change 1982 to 1996 patent count; EPTL = express package transportation and logistics.

[2] Griliches, Z. 1990. "Patent statistics as economic indicators: a survey." *J. Economic Literature*. 25: 1661–1707.

Year-by-year trends in U.S. patent counts in each sector are compared in Figure 1. The dominant sector is information technology, which has increased more than 300 percent, from under 4,000 per year in 1982 to just over 16,000 per year in 1996. As a result of this rapid growth, information technology sector patents accounted for about 15 percent of all U.S. patents issued in 1996.

Over the same period, health—the second largest of the five sectors—grew 189 percent to nearly 5,000 patents; advanced materials grew more than 300 percent to approximately 1,200; EPTL grew 151 percent to over 1,500; and automotive grew 105 percent to about 2,700 per year. The growth rates for all but the automotive sector were much higher than the 89 percent overall growth rate of patents in the U.S. patent system, and even the automotive sector outpaced the overall rate.

Information technology sector patents accounted for about 15 percent of all U.S. patents issued in 1996.

There has been a slight drop-off in advanced materials patents from their high in 1993, coinciding with the peak and drop-off of superconductor patenting[3] in the U.S. patent system.

Patenting Activity by Country

At current growth rates, Korea and Taiwan will overtake the U.K. in the number of patents granted in the U.S. system in a relatively short time.

With nearly half of all U.S. patents being granted to foreign inventors, the U.S. system is considered to be the most level playing field for comparing international patenting.[4] In fact, there is a strong correlation between the extent to which inventors patent in the U.S. patent system and the gross domestic product of their home countries.[5]

In Figures 2 and 3 we compare trends in patenting in the U.S. patent system for each of the 15 countries and the EU. Because the patent

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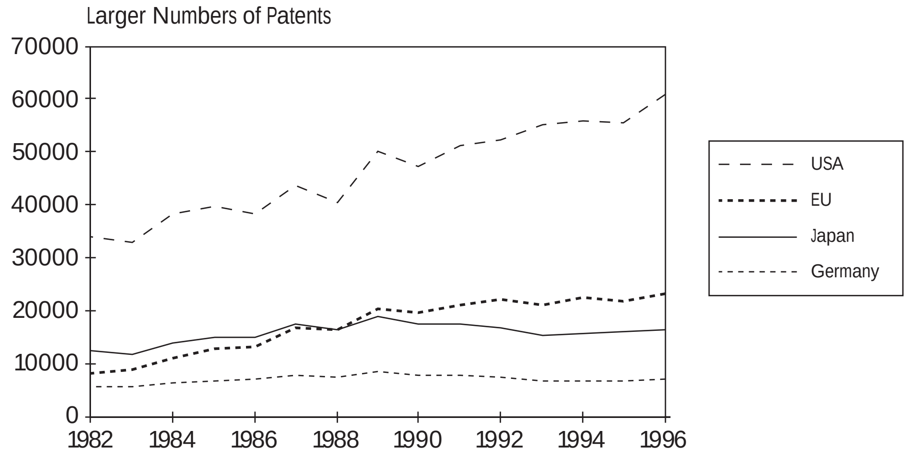
[3] Kayal, Aymen A. January 1997. “An empirical evaluation of the technology cycle time indicator as a measure of the pace of technological progress in the superconductor technology.” PhD dissertation. School of Engineering and Applied Science, The George Washington University, Washington, DC.

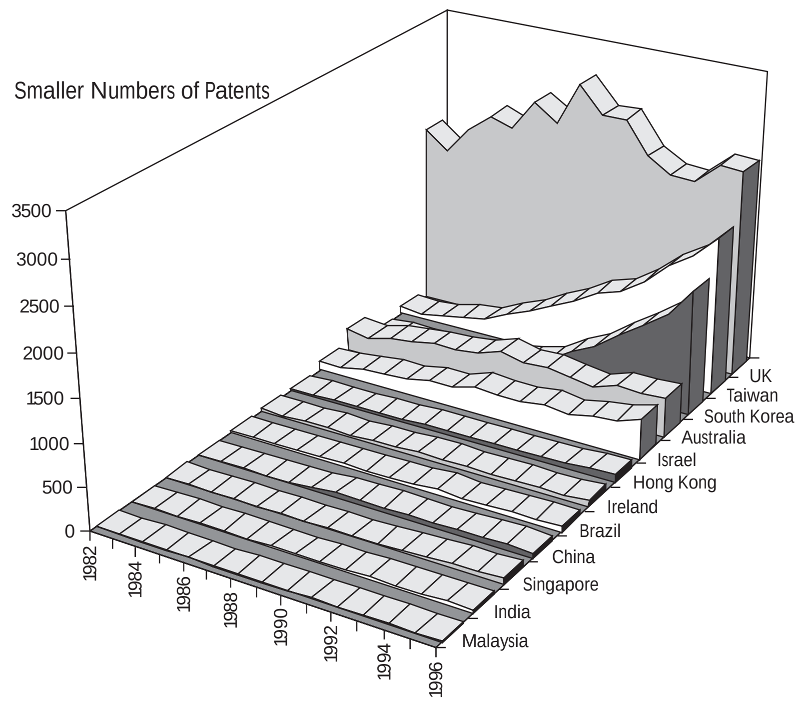
[4] Pavitt, K. 1985. Patent statistics as indicators of innovative activities: possibilities and problems. *Scientometrics*. 7: 1–2.

[5] Narin, F. 1991. “Globalization of research, scholarly information and patents—ten year trends.” Proceedings of the North American Serials Interest Group 6th Annual Conference, June 14–17, 1991. *The Serials Librarian*. 21: 2–3.

Figure 2. Total U.S. Patent Trends by Inventor Country and Grant Year (1982–96)

(Note different scales)

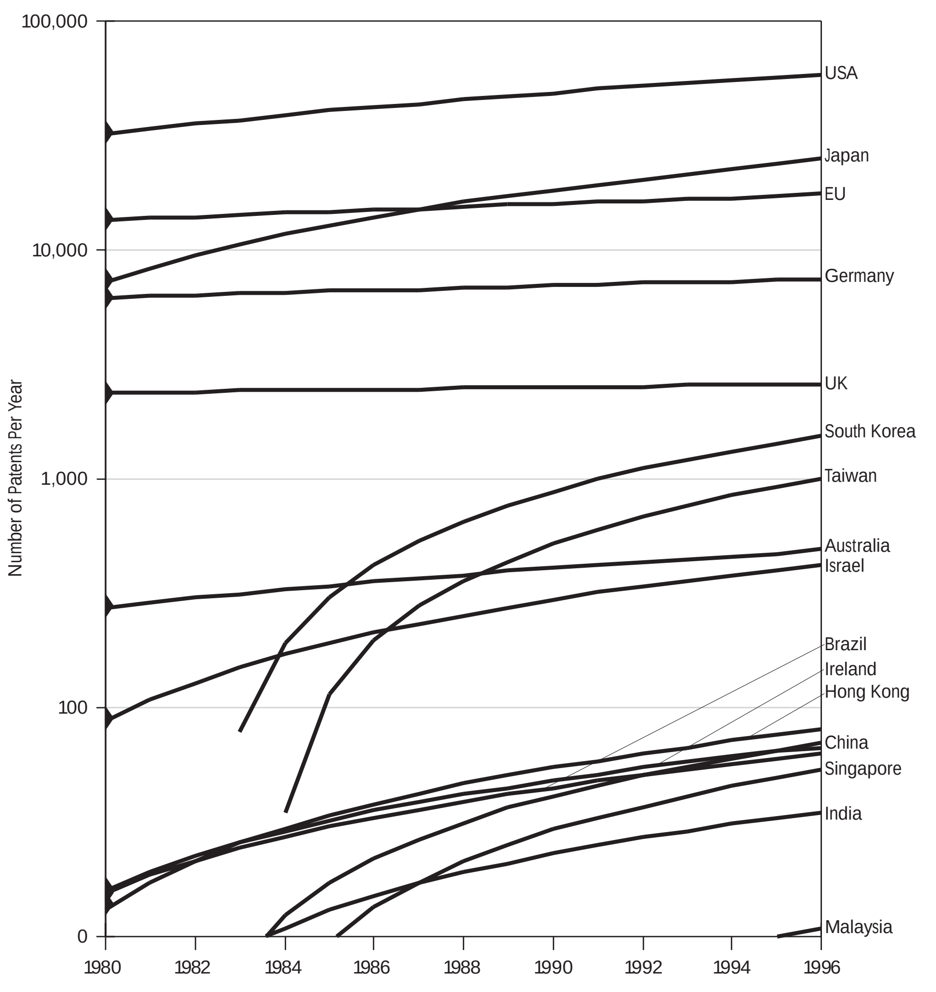




counts for the countries in this study cover such a wide range, Figure 2 is split into two charts with different scales. Figure 3 provides the same data in a single chart that uses a semi-log format.

The United States dominates the patent counts and, in fact, its share has grown slightly after bottoming out around 1990. From 1991–1996 the U.S.-invented share was 55 percent of all U.S. patents granted. Japan came in second with slightly more than 20 percent of U.S. patents in recent years, Germany third with about 7 percent, and the U.K. fourth with about 2 percent.

Figure 3. U.S. Patent Activity by Inventor Country and Grant Year



The United States dominates the patent counts and, in fact, its share has grown slightly after bottoming out around 1990.

In the past two years, Korea and Taiwan were granted more U.S. patents in information technology than either the U.K. or Germany.

Table 2. U.S. Patent Counts by Inventor Country

Inventor Country	U.S. Patent Counts 1982–96	Percentage of 1982–96 U.S. Patents
All Patents	1,276,351	100
U.S.	694,796	54
Japan	257,627	20
Germany	103,801	8.1
U.K.	37,301	2.9
Taiwan	10,836	0.85
Australia	6,037	0.47
Korea	5,899	0.46
Israel	4,072	0.32
Hong Kong	725	0.06
Ireland	671	0.05
Brazil	615	0.05
China	533	0.04
Singapore	354	0.03
India	310	0.02
Malaysia	86	0.01

German, U.K., and EU patenting in the United States has remained fairly constant, while Japanese patenting has been increasing, surpassing the EU in the late 1980s. What is most noticeable here is the strong growth in U.S. patents for Taiwan and Korea. At current growth rates, both will overtake the U.K. in a relatively short time.

Among the smaller patenting countries (see the grouping at the bottom of Figure 3), China and Singapore have experienced the fastest growth. Table 2 compares 15-year total U.S. patent counts and percentages for the 15 countries. The seven countries listed at the bottom of the table each have been granted fewer than 1,000 U.S. patents. Malaysia has yet to be granted even 100.

Patenting Activity by Sector and Country

In the past two years, Korea and Taiwan were granted more U.S. patents in information technology than either the U.K. or Germany.

For the most part, the analysis presented in the remainder of the report is based on indicators computed for three five-year periods: 1982–1986, 1987–1991, and 1992–1996. Patent counts are tabulated by sector in the three periods in Tables 3A and 3B and plotted in Figure 4. Split scales are used in Figure 4 to enable distinctions to be made more easily over a very wide range of patent counts.

In the 1992–1996 patent counts, the order of the top four leaders is the same across all sectors but health—the United States, Japan, the EU as a whole, and Germany. In the health sector, where the U.S. lead over Japan is the widest, the order is the United States, EU, Japan, and Germany. The United States also has a strong lead in the EPTL sector. U.S. leadership in advanced materials and automotive is not as strong as in health and EPTL, and the U.S. lead is narrowest in information technology.

Although the U.K. ranks fifth in all sectors except information technology—where Korea ranks slightly ahead of the U.K. in 1992–1996 counts—the U.K. is a major player only in health.[6]

The technological capacities of Korea and Taiwan are budding, with their growing strength most evident in the advanced materials and information technology sectors. Since 1995, both Korea and Taiwan have exceeded the U.K. and Germany in information technology patents issued. Israel and Australia are emerging innovators in information technology as well as health. Taiwan, Korea, Australia, and Israel are showing steadily growing strength in EPTL patents.

The technological capacities of Korea and Taiwan are budding, with their growing strength most evident in the advanced materials and information technology sectors.

On the other hand, Hong Kong, Malaysia, and Singapore do not have enough patenting activity in any of these sectors to be identified as emerging competitors. This fact could reflect these countries' lack of a significant indigenous research and development (R&D) capability. For the most part, manufacturing and industrial development in these countries is currently supported by R&D carried out elsewhere; this situation may change in the future as these countries continue to build their technological infrastructure.

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[6] The U.K. is not nearly as significant a player in the health sector as we had expected. However, we have verified that the data shown here are reasonable by checking the CHI Research TP2 International Technology Indicators database, which partitions patents by broad Standard Industrial Code (SIC) categories, one of which is SIC 14 Drugs and Medicines. While the absolute counts in the SIC are considerably lower than the counts found here, the relative patenting for the United States, Japan, Germany, and the U.K. in TP2 and in this study match very closely.

Table 3A. U.S. Patent Counts by Sector, Inventor Country, and Grant Date Period

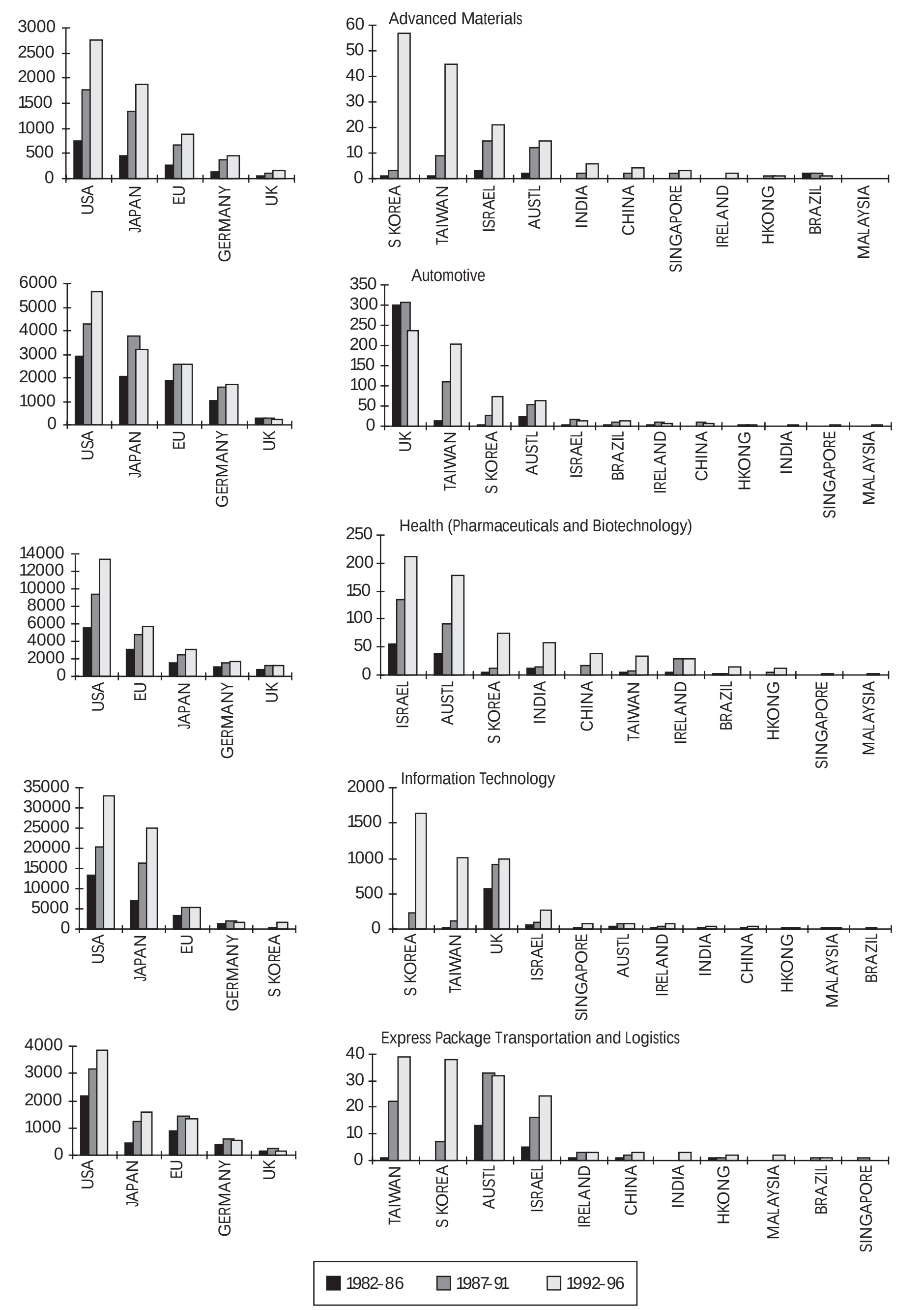
Sector	Adv. Materials			Automotive			Health			Info Tech			EPTL			All		
Country	***1982–86***	***1987–91***	***1992–96***	***1982–86***	***1987–91***	***1992–96***	***1982–86***	***1987–91***	***1992–96***	***1982–86***	***1987–91***	***1992–96***	***1982–86***	***1987–91***	***1992–96***	***1982–86***	***1987–91***	***1992–96***
Australia	2	12	15	25	54	65	38	92	178	37	70	80	13	33	32	1,523	2,201	2,174
Brazil	2	2	1	3	9	12	2	2	14	0	3	6	0	1	1	123	207	28.5
China	0	2	4	0	10	7	1	16	38	2	21	36	1	2	3	16	230	288
EU	273	676	894	1,891	2,595	2,580	3,086	4,798	5,622	3,373	5,388	5,409	912	1,413	1,319	67,721	87,419	79,972
Germany	147	374	464	1,046	1,579	1,697	1,001	1,523	1,617	1,304	1,937	1,712	404	576	528	30,843	38,861	34,097
Hong Kong	0	1	1	1	2	3	1	4	12	7	7	26	1	1	2	118	236	372
India	0	2	6	0	0	3	11	15	57	1	4	41	0	0	3	59	85	166
Ireland	0	0	2	3	9	7	6	28	28	11	30	75	1	3	3	127	256	289
Israel	3	15	21	5	16	12	56	135	211	53	102	258	5	16	24	774	1,426	1,872
Japan	463	1,329	1,862	2,058	3,754	3,217	1,497	2,510	3,008	7,012	16,208	25,015	432	1,215	1,560	54,053	93,451	110,124
Malaysia	0	0	0	1	0	0	0	0	2	2	4	10	0	0	2	13	23	50
Singapore	0	2	3	1	0	0	0	0	3	1	8	82	0	1	0	26	65	263
So Korea	1	3	57	2	27	72	5	12	74	4	224	1,629	0	7	38	157	968	4,912
Taiwan	1	9	45	15	109	204	4	8	34	12	113	1,007	1	22	39	640	3,040	7,156
UK	49	107	166	299	308	236	820	1,194	1,271	575	921	982	137	224	163	11,302	14,073	11,926
USA	741	1,761	2,764	2,897	4,273	5,671	5,477	9,339	13,457	13,202	20,224	32,852	2,162	3,161	3,885	182,462	232,533	279,801
All patents for sector	1,548	4,075	6,054	7,304	11,428	12,209	10,863	17,799	23,595	23,977	42,548	65,583	3,734	6,206	7,206	324,426	443,322	508,603

Table 3B. U.S. Patent Percent by Sector, Inventor Country, and Grant Date Period

Sector	Adv. Materials			Automotive			Health			Info Tech			EPTL			All		
Country	***1982–86***	***1987–91***	***1992–96***	***1982–86***	***1987–91***	***1992–96***	***1982–86***	***1987–91***	***1992–96***	***1982–86***	***1987–91***	***1992–96***	***1982–86***	***1987–91***	***1992–96***	***1982–86***	***1987–91***	***1992–96***
Australia	0.13	0.29	0.25	0.34	0.47	0.53	0.35	0.52	0.75	0.15	0.16	0.12	0.35	0.53	0.44	0.47	0.50	0.43
Brazil	0.13	0.05	0.02	0.04	0.08	0.10	0.02	0.01	0.06	0.00	0.01	0.01	0.00	0.02	0.01	0.04	0.05	0.06
China	0.00	0.05	0.07	0.00	0.09	0.06	0.01	0.09	0.16	0.01	0.05	0.05	0.03	0.03	0.04	0.00	0.05	0.06
EU	17.64	16.59	14.77	25.89	22.71	21.13	28.41	26.96	23.83	14.07	12.66	8.25	24.42	22.77	18.30	20.87	19.72	15.72
Germany	9.50	9.18	7.66	14.32	13.82	13.90	9.21	8.56	6.85	5.44	4.55	2.61	10.82	9.28	7.33	9.51	8.77	6.70
Hong Kong	0.00	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.05	0.03	0.02	0.04	0.03	0.02	0.03	0.04	0.05	0.07
India	0.00	0.05	0.10	0.00	0.00	0.02	0.10	0.08	0.24	0.00	0.01	0.06	0.00	0.00	0.04	0.02	0.02	0.03
Ireland	0.00	0.00	0.03	0.04	0.08	0.06	0.06	0.16	0.12	0.05	0.07	0.11	0.03	0.05	0.04	0.04	0.06	0.06
Israel	0.19	0.37	0.35	0.07	0.14	0.10	0.52	0.76	0.89	0.22	0.24	0.39	0.13	0.26	0.33	0.24	0.32	0.37
Japan	29.91	32.61	30.76	28.18	32.85	26.35	13.78	14.10	12.75	29.24	38.09	38.14	11.57	19.58	21.65	16.66	21.08	21.65
Malaysia	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.02	0.00	0.00	0.03	0.00	0.01	0.01
Singapore	0.00	0.05	0.05	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.13	0.00	0.02	0.00	0.01	0.01	0.05
So Korea	0.06	0.07	0.94	0.03	0.24	0.59	0.05	0.07	0.31	0.02	0.53	2.48	0.00	0.11	0.53	0.05	0.22	0.97
Taiwan	0.06	0.22	0.74	0.21	0.95	1.67	0.04	0.04	0.14	0.05	0.27	1.54	0.03	0.35	0.54	0.20	0.69	1.41
UK	3.17	2.63	2.74	4.09	2.70	1.93	7.55	6.71	5.39	2.40	2.16	1.50	3.67	3.61	2.26	3.48	3.17	2.34
USA	47.87	43.21	45.66	39.66	37.39	46.45	50.42	52.47	57.03	55.06	47.53	50.09	57.90	50.93	53.91	56.24	52.45	55.01
All patents for sector	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Tables sorted by 1992-96 ALL sector patent counts

Figure 4. U.S. Patent Counts by Sector, Country, and Period



The Activity Index

What It Is

The AI is the ratio of the percent of a country's patents in a particular sector to the percent of all U.S. patents in the sector.

Why It's Important

AI values provide a way to gauge a country's relative technological emphasis.

How It's Calculated

AI is defined as the percentage of a country's U.S. patents in a sector, divided by the percentage of all U.S. patents in that sector. An AI value of 1.0 would indicate that the nation's emphasis in a given technology sector is in proportion to the overall patent distribution of the U.S. system. For example, if 15 percent of all U.S. patents are in information technology, one would expect 15 percent of a given country's patents to be in information technology (i.e., 15 percent divided by 15 percent yields an AI value of 1.0).

To the extent that a country's share of patents in information technology exceeds the percentage of all U.S. patents in information technology, the country has an emphasis in information technology. For example, if a country has 30 percent of its patents in information technology, and 15 percent of all U.S. patents are in information technology, then its AI value would be 2.0 (30 percent divided by 15 percent). An AI value of 2.0 means that a country has twice the expected emphasis in a sector. To the extent that a country has an AI of less than 1.0, the country does not emphasize information technology. For example, a country that has 7.5 percent of its patents in information technology has an AI value of 0.5 (7.5 percent divided by 15 percent).

It is important to note that because the United States is the leader in all these sectors and makes up over half the patent system, U.S. AI values will not stray far from the value of 1.0.

What Do the Data Show?

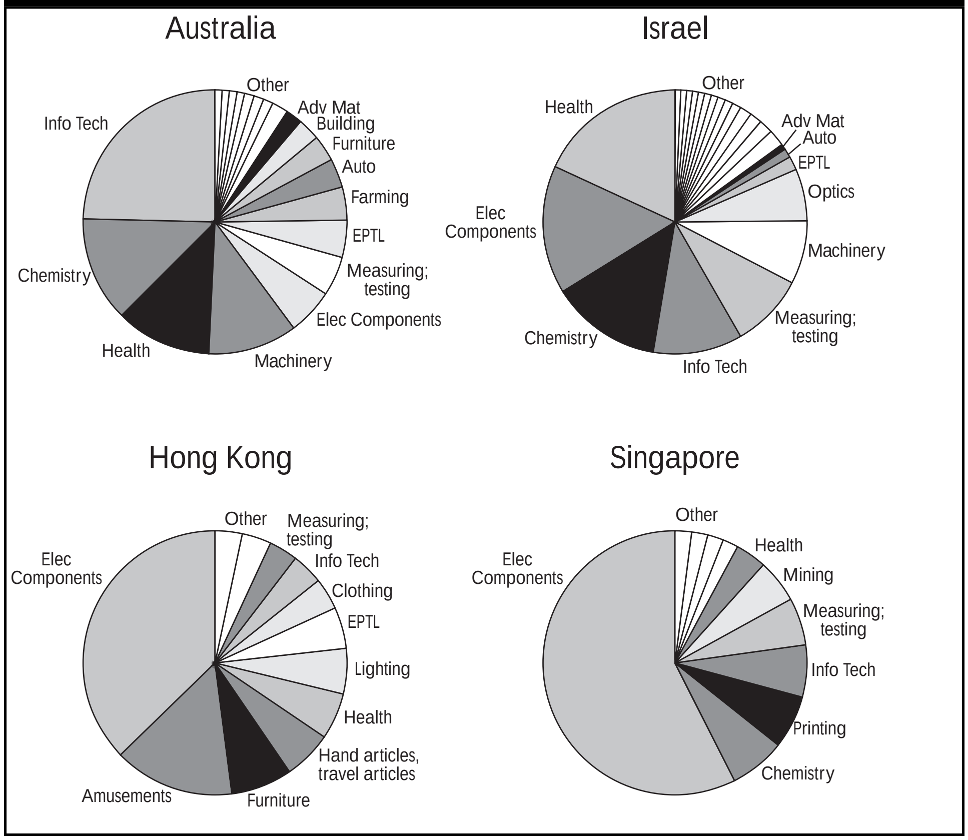
AI values for key countries in each sector are presented in Figure 6.

Advanced Materials

Among countries with a significant number of patents, Japan has high AI values, while those for Australia and Taiwan are relatively low.

Brazil and Germany have high AI values in the automotive sector.

Figure 5A. Major Patenting Areas for Smaller Patenting Countries (1992–96)



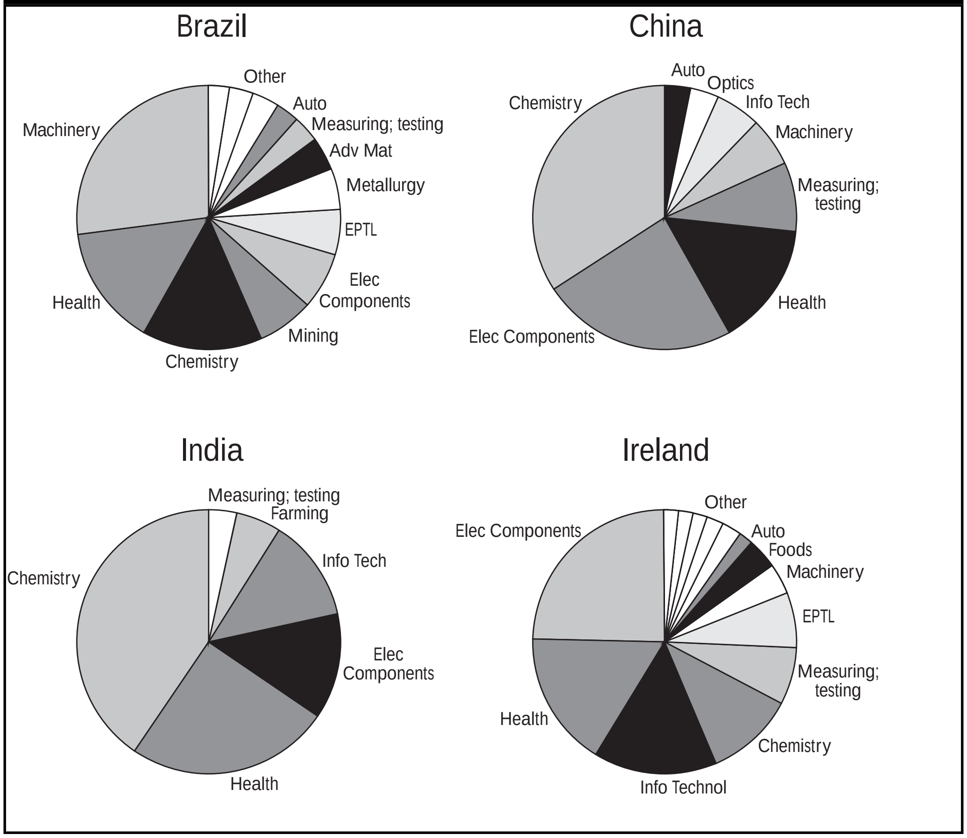
Automotive

Brazil and Germany have high AI values in the automotive sector. Israel has low AI values in automotive, suggesting that it is placing its emphasis elsewhere. Japan's AI values in automotive have declined as it shifts its emphasis to other sectors, such as EPTL.

Health

Several countries including China, India, Ireland, Israel, and the U.K. have a relatively high emphasis in the health sector. Korea and Taiwan have relatively low AI values in health. Please note that the AI values for India are extremely high (7.4 in 1992–1996), but that they have been truncated in the chart. Japan's historically low emphasis on health—with AI values less than 1.0 in each of the three five-year periods—continues to decline.

Figure 5B. Major Patenting Areas for Smaller Patenting Countries (1992–96)



Information Technology

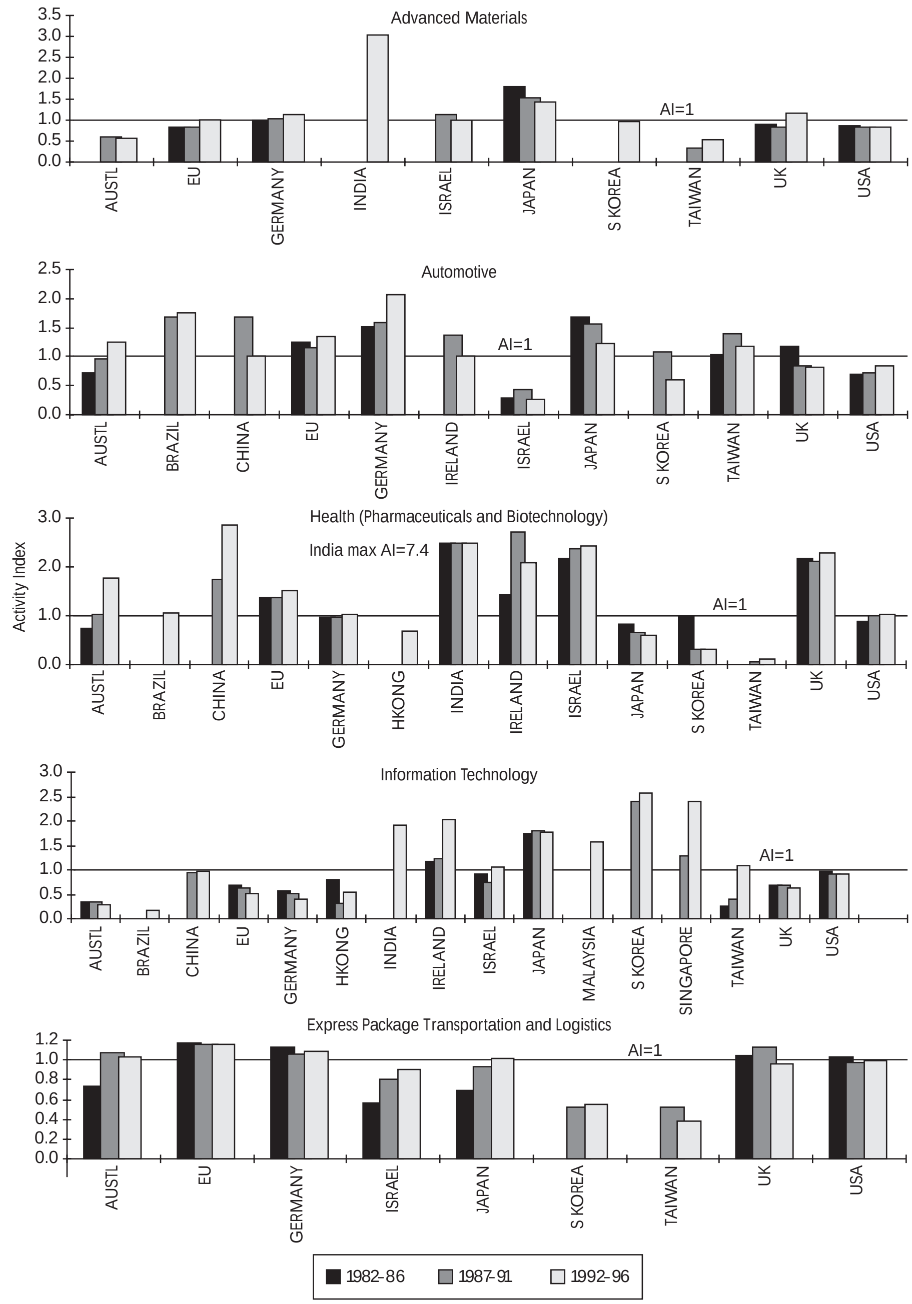
Countries with a high emphasis on information technology include India, Ireland, Japan, Malaysia, Korea, and Singapore. AI values for this sector are particularly low for Australia, Brazil, and Germany.

EPTL

All the countries have AI values close to 1.0, with the exception of Korea and Taiwan, which show low emphasis in this sector.

Figure 6. U.S. Patent Activity Index (AI) by Sector, Country, and Period

(Countries arranged alphabetically. Countries with < 5 patents in sector and period not shown.)



Activity Index = % of Country's Patents in Sector / % of All Patents in Sector

IMPACT AND TECHNOLOGICAL STRENGTH

The Current Impact Index

What It Is

CII is an indicator of the quality of a country's patent portfolio in a particular sector.

Why It's Important

The number of times a patent is cited in another patent is a measure of the extent to which current technology is building on a patent. Highly cited patents tend to be of higher technological impact.[7] As a general rule, 70 percent of all patents are never cited, or cited only one or two times in the first five years. Therefore, for some technologies, having just five citations places a patent in the top few percent based on citations received.

How It's Calculated

CII counts the number of times a country's patents are cited in a particular sector over a five-year period. This number is then divided by the expected number of citations to all patents in the sector in the same years. If the actual number of citations equals the expected number of citations, the CII value is 1.0. CII values greater than 1.0 indicate a higher level of citations than would be expected, and thus indicate patents with a higher technological impact. CII values less than 1 indicate patents with a lower degree of technological impact. For example, a CII value of 1.1 indicates that there are 10 percent more citations than expected. A CII value of more than 3.0 is usually considered to be very high, and CII values rarely go above 5.0. Thus, the CII is a measure of the impact a country's earlier patents have had on recent technology developments.

Technical Information About the Index

CII is a synchronous indicator, meaning that it uses a rolling five-year period, moving with the current year and looking back five years. For example, a CII value for 1995 is based on citations for the years 1990–1994; a CII value for 1996 is based on citations for the years 1991–1995, and so on. As a result, when a country's recent patents start to drop in

[7] Albert, M., D. Avery, F. Narin, and P. McAllister. 1991. "Direct validation of citation counts as indicators of industrially important patents." *Research Policy*. 20: 251–259.

impact, this fact is promptly reflected as a decline in the current year's CII. The CII is a normalized index, which means that CII values computed in different years can be compared, and CII values for multiple years can be computed as weighted averages.

The normalization base for the CII values is the set of all patents in each year. Because patent citation frequency varies from technology to technology, the CII comparison should always be among sets of patents in similar technology areas, as is the case with this study.

CII values are tabulated by sector and period in Tables 4A and 4B and shown graphically in the charts in Figure 7. In cases for which there are insufficient patents to compute a CII value (e.g., if there are fewer than 10 patents for a country in the sector in the five prior years), no CII value is shown in Tables 4A and 4B.

What Do the Data Show?

Advanced Materials

Comparing the 1992–1996 period with the 1987–1991 period, the absolute CII values for the top countries patenting in the advanced materials sector dropped. At first glance, this fact appears to indicate that advanced materials is no longer a "hot" area of research. However, upon closer examination, the decline may indicate that a consolidation is taking place in some sub-areas that have proportionately more patents than other sub-areas, such as in high-temperature superconductors.

Automotive

The drop in CII for Japan may indicate that Japan has relinquished the quality lead it held over the United States for some years, just as it has lost its numerical lead in patents. The CII values for the 1992–1996 period are virtually the same for the United States, Japan, and Germany. Most other countries, including the U.K., have significantly lower CII values.

Taiwan's automotive sector CII value has increased dramatically and now leads both Japan and the United States. However, it is more difficult for a country with large numbers of patents in a sector to attain a high CII value than it is for a country with relatively few patents in a sector. Still, Taiwan does have some highly cited automotive patents.

Figure 7. Current Impact Index (CII) by Sector, Country, and Period

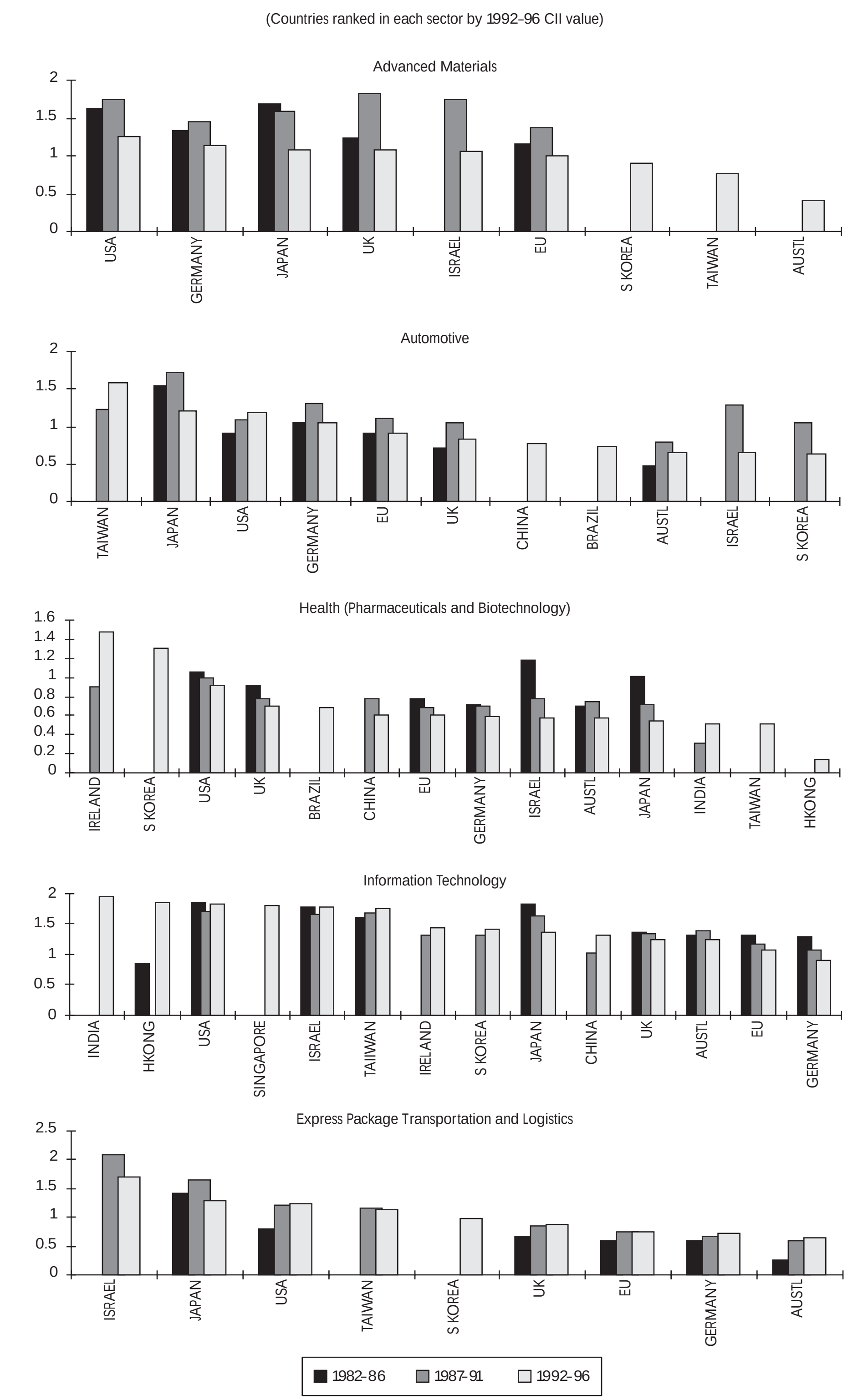


Table 4A. Current Impact Index by Sector, Inventor Country, and Grant Date Period

Sector	Adv. Materials			Automotive			Health			Info Tech			EPTL			All		
Country	***1982–86***	***1987–91***	***1992–96***	***1982–86***	***1987–91***	***1992–96***	***1982–86***	***1987–91***	***1992–96***	***1982–86***	***1987–91***	***1992–96***	***1982–86***	***1987–91***	***1992–96***	***1982–86***	***1987–91***	***1992–96***
Australia	*	*	0.41	0.47	0.79	0.66	0.70	0.74	0.57	1.30	1.39	1.23	0.26	0.60	0.64	0.65	0.68	0.71
Brazil	*	*	*	*	*	0.73	*	*	0.68	*	*	*	*	*	*	0.54	0.52	0.54
China	*	*	*	*	*	0.78	*	0.78	0.61	*	1.03	1.32	*	*	*	*	0.78	0.68
EU	1.16	1.37	1.00	0.91	1.11	0.91	0.77	0.68	0.60	1.32	1.17	1.06	0.59	0.74	0.76	# N/A	# N/A	# N/A
Germany	1.34	1.46	1.13	1.05	1.30	1.04	0.72	0.70	0.59	1.29	1.08	0.91	0.58	0.68	0.71	0.86	0.78	0.69
Hong Kong	*	*	*	*	*	*	*	*	0.14	0.84	*	1.85	*	*	*	*	0.99	0.96
India	*	*	*	*	*	*	*	0.31	0.52	*	*	1.94	*	*	*	*	0.45	0.70
Ireland	*	*	*	*	*	*	*	0.90	1.47	*	1.31	1.44	*	*	*	0.74	0.90	1.00
Israel	*	1.75	1.05	*	1.28	0.66	1.18	0.77	0.58	1.76	1.65	1.76	*	2.09	1.69	0.88	0.91	0.95
Japan	1.69	1.59	1.07	1.55	1.73	1.20	1.01	0.72	0.54	1.83	1.63	1.37	1.42	1.65	1.29	1.27	1.23	1.06
Malaysia	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0.98	0.64
Singapore	*	*	*	*	*	*	*	*	*	*	*	1.79	*	*	*	*	0.73	1.16
So Korea	*	*	0.91	*	1.05	0.63	*	*	1.31	*	1.31	1.40	*	*	0.99	0.57	0.71	0.88
Taiwan	*	*	0.76	0.00	1.23	1.59	*	*	0.52	1.61	1.68	1.75	*	1.17	1.14	0.68	0.80	0.95
UK	1.23	1.83	1.07	0.72	1.04	0.83	0.91	0.77	0.70	1.36	1.34	1.25	0.67	0.85	0.88	0.93	0.88	0.78
USA	1.63	1.75	1.26	0.92	1.09	1.19	1.06	1.00	0.91	1.85	1.71	1.82	0.81	1.22	1.24	1.02	1.03	1.10
Sector 15 Countries Total	1.60	1.64	1.15	1.05	1.31	1.13	1.00	0.90	0.80	1.76	1.60	1.55	0.83	1.21	1.18	—	—	—

* Insufficient patents to compute CII

Table 4B. Technological Strength by Sector, Inventor Country, and Grant Date Period

Sector	Adv. Materials			Automotive			Health			Info Tech			EPTL			All		
Country	***1982–86***	***1987–91***	***1992–96***	***1982–86***	***1987–91***	***1992–96***	***1982–86***	***1987–91***	***1992–96***	***1982–86***	***1987–91***	***1992–96***	***1982–86***	***1987–91***	***1992–96***	***1982–86***	***1987–91***	***1992–96***
Australia	*	*	6	12	43	43	27	68	101	48	97	98	3	20	20	994	1,505	1,539
Brazil	*	*	*	*	*	9	*	*	10	*	*	*	*	*	*	66	109	154
China	*	*	*	*	*	5	*	12	23	*	22	48	*	*	*	*	179	197
EU	317	926	894	1,721	2,880	2,348	2,376	3,263	3,373	4,452	6,304	5,734	538	1,046	1,002	# N/A	# N/A	# N/A
Germany	197	546	524	1,098	2,053	1,765	721	1,066	954	1,682	2,092	1,558	234	392	375	26,457	30,231	23,550
Hong Kong	*	*	*	*	*	*	*	*	2	6	*	48	*	*	*	*	233	357
India	*	*	*	*	*	*	*	5	30	*	*	80	*	*	*	*	38	116
Ireland	*	*	*	*	*	*	*	25	41	*	39	108	*	*	*	94	231	288
Israel	*	26	22	*	20	8	66	104	122	93	168	454	*	33	41	685	1,291	1,772
Japan	782	2,113	1,992	3,190	6,494	3,860	1,512	1,807	1,624	12,832	26,419	34,271	613	2,005	2,012	68,779	115,377	117,265
Malaysia	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	22	32
Singapore	*	*	*	*	*	*	*	*	*	*	*	147	*	*	*	*	48	306
So Korea	*	*	52	*	28	45	*	*	97	*	293	2,281	*	*	38	90	685	4,332
Taiwan	*	*	34	0	134	324	*	*	18	19	190	1,762	*	26	44	437	2,426	6,813
UK	60	196	178	215	320	196	746	919	890	782	1,234	1,228	92	190	143	10,463	12,328	9,354
USA	1,208	3,082	3,483	2,665	4,658	6,748	5,806	9,339	12,246	24,424	34,583	59,791	1,751	3,856	4,817	185,730	240,311	308,003
Sector 15 Countries Total**	2,234	5,838	5,978	7,227	14,151	13,148	8,805	13,038	15,328	41,409	67,101	100,581	2,611	6,330	7,303	—	—	—

*Insufficient patents to compute CII

**Sector 15 country totals exclude the EU except for Auto and InfoTech

Health

Among the countries with significant numbers of health sector patents (the United States, Japan, Germany, the U.K., Israel, and Australia), the United States has the highest CII, followed by the U.K., with the others tied for third.

Information Technology

Among countries with significant numbers of patents, the United States is the CII leader, followed by the U.K., Korea, and Japan—which are roughly tied for second—and Germany, which is ranked somewhat lower.

EPTL

The CII values for Japan and the United States are nearly identical in the EPTL sector and considerably higher than the CII values of the U.K. and Germany.

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Technological Strength

The combination of much higher patent counts and relatively high CII values makes the United States the undisputed leader in technological strength.

What It Is

The TS indicator provides a quality-weighted measure of a nation's technological strength, using both the size and quality of a nation's patents.

Why It's Important

The raw number of patents is a measure of technological size, though it does not in any way reflect the quality of the patent portfolio. Neither the raw number of patents nor the quality of the patent portfolio is sufficient, in and of itself, to gauge the technological strength of a country. The TS indicator incorporates both number and quality to arrive at a quality-weighted measure of technological size.

How It's Calculated

The TS value is calculated by multiplying the number of a nation's patents in a sector by its CII value in that sector. Thus, the TS value of a high-impact portfolio is magnified by its relatively high CII, and the converse is also true.

What Do the Data Show?

TS values for each sector are listed in Table 4 and plotted in Figure 8 using a split scale because of the wide range of values among nations. In a few cases, TS values for a country are plotted on both scales to provide a view of another slice of the data.

The combination of much higher patent counts and relatively high CII values currently makes the United States the undisputed leader in technological strength. This was not always so; in earlier years, Japan's automotive sector TS was significantly higher than that of the United States. However, with the decline in Japanese automotive patenting in the United States, that situation has been reversed. It is interesting to note that Taiwan has a 1992–1996 automotive patent count approaching that of the U.K., which, when coupled with its higher CII, gives Taiwan a TS value well above that of the U.K.

Year-by-Year TS Trends

TS values for the major countries are plotted year-by-year for each sector in Figure 9. The United States recaptured the technological lead in the automotive sector from Japan in the early 1990s, as measured by the TS indicator. The United States now has the technological lead in all sectors, with its widest margin in health.

The United States recaptured the technological lead in the automotive sector from Japan in the early 1990s.

- Beginning in the early 1980s—even before the Japanese share of the U.S. automotive market became so significant—Japan led the United States in technological strength in the automotive sector. However, the TS trend for the United States in the automotive sector began to improve in the late 1980s; at about the same time, Japan's automotive TS began to decline. About five years ago, the United States regained the TS lead in that sector.

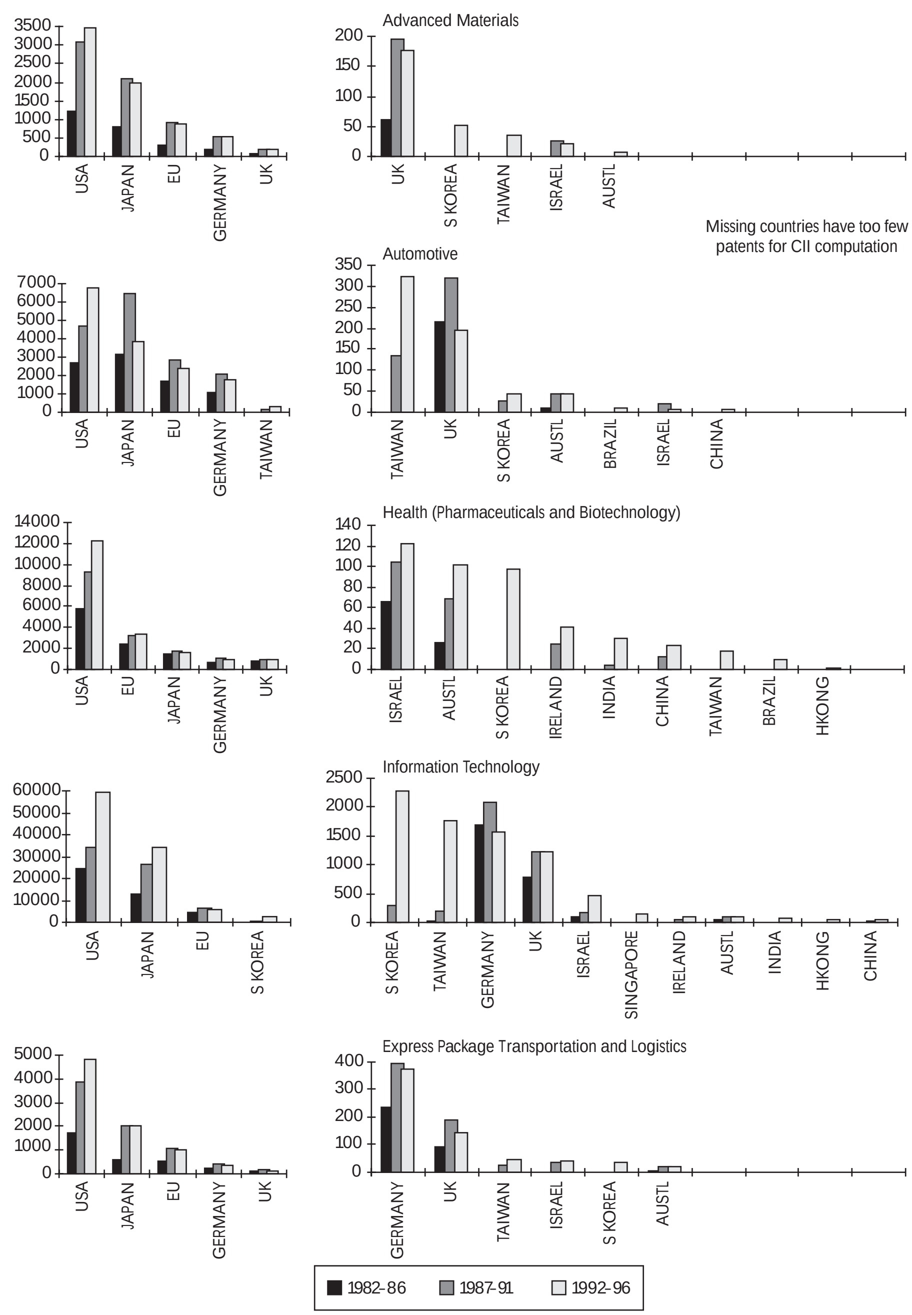
- In all sectors but advanced materials, the United States leads by a large margin. The advanced materials TS values for both the United States and Japan dropped significantly after 1991 as a result of declining patent counts and a more significant drop in CII values.

- In the health sector, U.S. primacy is unquestioned.

- In information technology, the United States has a commanding lead, and the gap between the United States and its next closest competitor, Japan, has widened significantly in recent years.

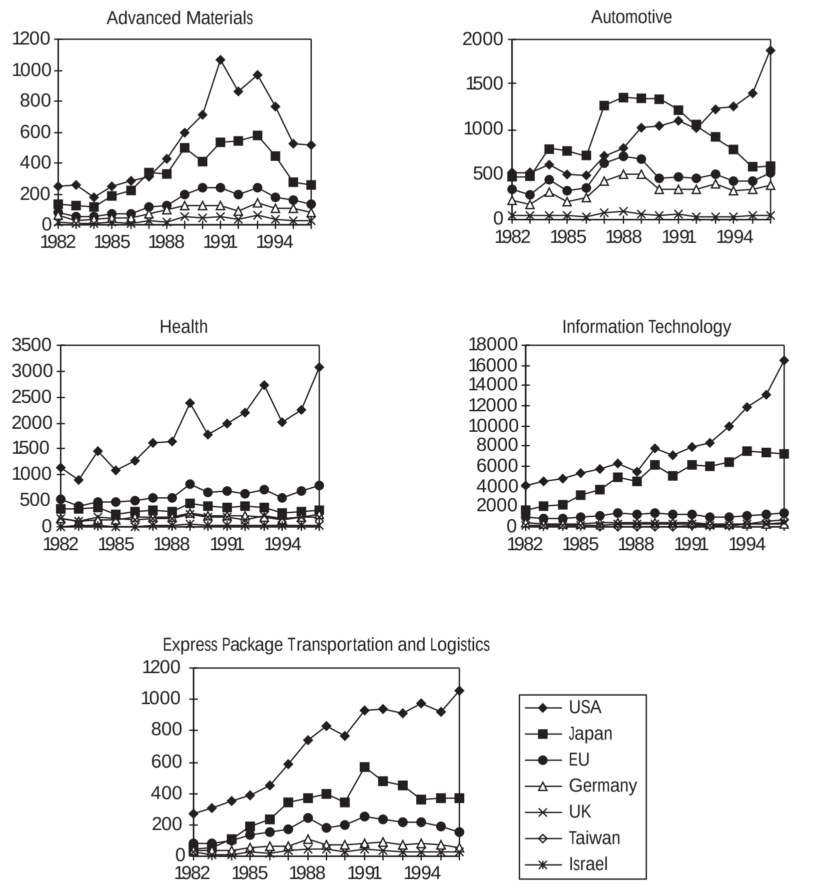
Figure 8. Technological Strength (TS)* Index by Sector, Country, and Period

(Note different scales and descending order of countries)



*TS = Number of Patents x CII

Figure 9. Technology Strength Trends



TECHNOLOGY POSITION

The general tendency in the U.S. patent system—both as a whole and within sectors—is toward faster cycle times (i.e., shorter times between succeeding generations of technology), as measured by TCT, and toward greater linkages between technology and basic science, as measured by the NPR score.

The general tendency in the U.S. patent system is toward faster cycle times and toward greater linkages between technology and basic science.

What They Are

TCT is the median age, in years, of U.S. patent prior-art examiner references listed on the front pages of a set of patents. The age is computed from the grant date of a cited patent to the grant date of each citing patent. Since the earlier technology cited in a new patent represents prior art, TCT is essentially the cycle time between generations of technology. Thus, the smaller the TCT value, the faster the technological turnover. Fast-moving technologies such as semiconductors have cycle times of under 5 years, whereas shipbuilding, a slow-moving technology, has a cycle time of 15 years.

NPR is the average count of U.S. patent front-page references to non-patent prior art. Thus, NPR is an indicator of the degree to which a group of patents is science-linked, building on leading-edge or basic research. The higher the NPR value, the greater the linkage to leading-edge or basic research.[8]

Why They're Important

Using these two indicators in combination provides a measure of the technological position of a country in a particular sector. Through our analysis, we sought to determine the pace of technological change in each sector and the degree of its linkage to leading-edge science.

How to Read the Charts

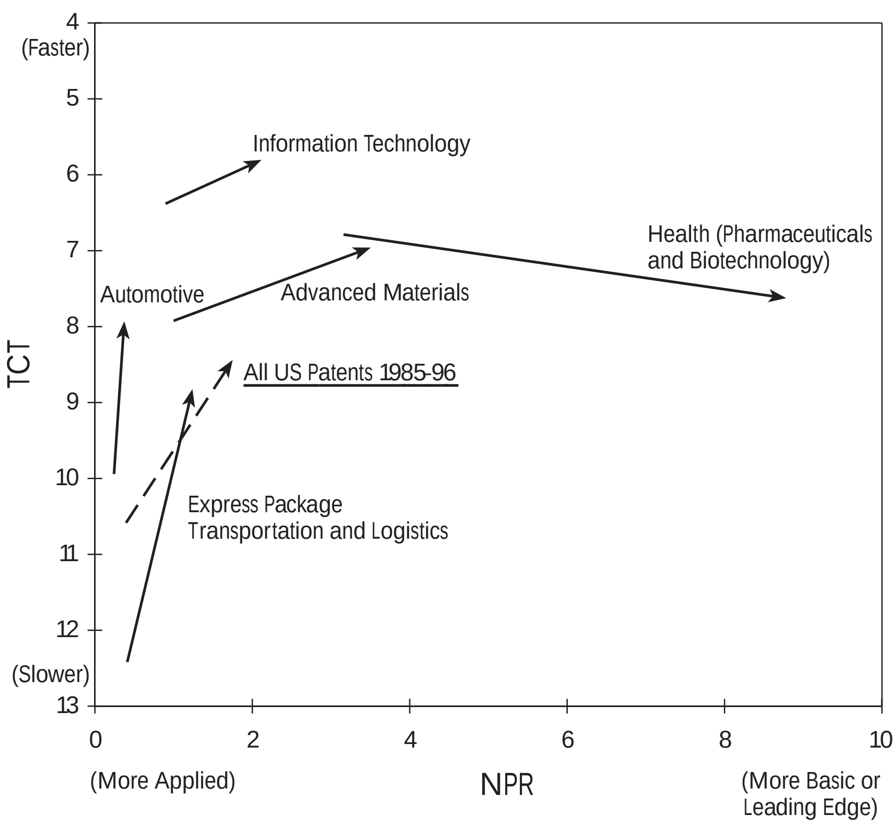
Figure 10 shows, for each sector, 1982–1996 TCT values plotted against 1982–1996 NPR values, using U.S. patents from all nations.[9] This figure provides a graphical view of the pace of technological change in each

[8] Carpenter, M., F. Narin, and P. Woolf. 1983. "Validation study: patent citations as indicators of science and foreign dependence." *World Patent Information.* 3,4: 60–163.

[9] A linear "best-fit" model was used to transform these data points into straight-line trajectories. An inverted TCT scale was used on the y-axis to provide for a more intuitive view of the data. By inverting the scale, an upward arrow—rather than a downward arrow—indicates a faster cycle time.

Figure 10. Technology Position Trajectories (TCT vs. NPR) for Each of the Five Sectors and for All U.S. Patents, 1982–96

(Note inverted TCT scales. Low values at top are fast; high values at bottom are slow)



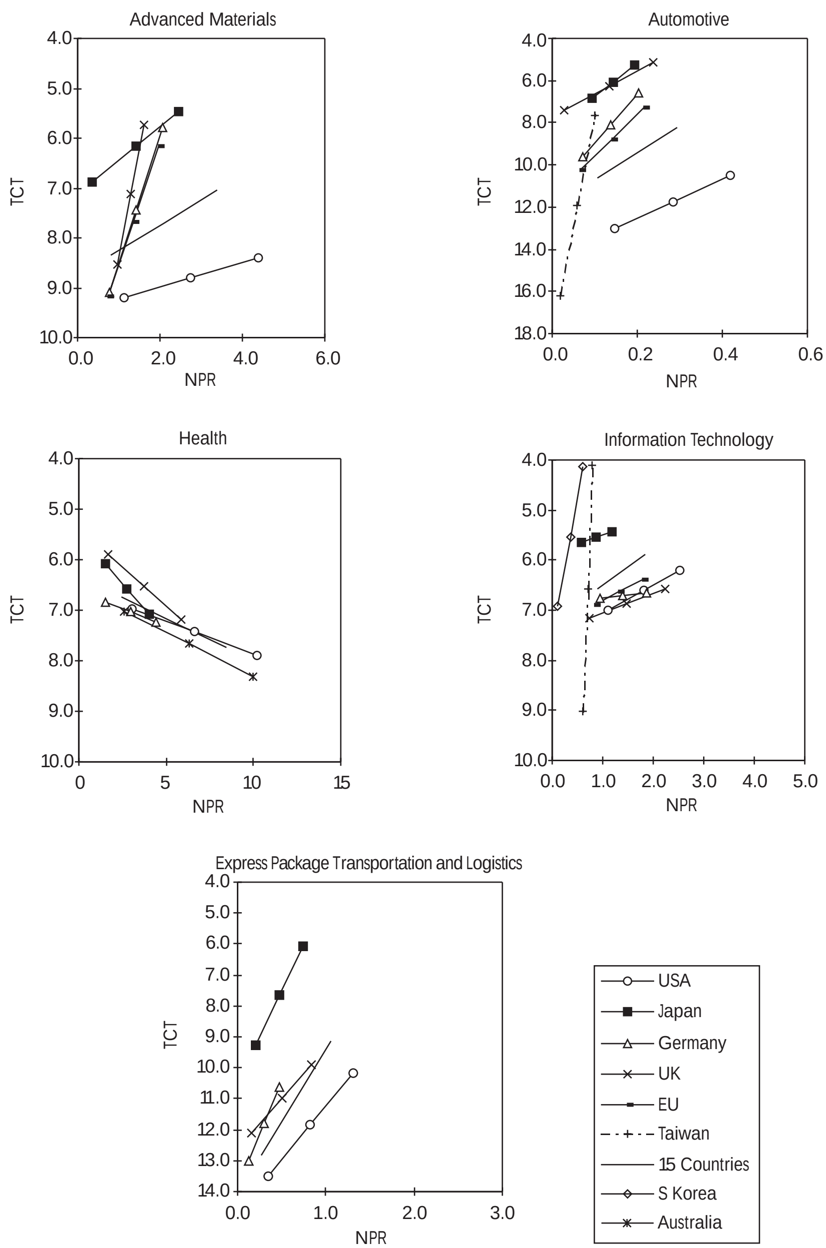
Linear best fit to 1982–86, 1987-91, and 1992–96 period NPR and TCT values

TCT = technology cycle time
NPR = non-patent reference

sector, its degree of linkage to leading-edge science, and the degree to which the pace of change and degree of linkage have changed over this 15-year period. The longer a sector's arrow, the greater the change it has undergone. The size of the vertical component of the arrow indicates the degree to which the cycle time has changed; the size of the horizontal component of the arrow indicates the degree to which its linkage to leading-edge science has changed. In Figure 11, these data are broken out and plotted for key countries in each sector to show their technology positions.

Figure 11. Technology Position Trajectories (NPR v. TCT)

(Note inverted TCT scales and very different NPR scale ranges)



Linear best fit to 1982–86, 87–91 and 92–97 NPR and TCT values

TCT = technology cycle time
NPR = non-patent reference

What Do the Data Show?

Figure 10 shows that there is increasing science linkage in all sectors, with the most dramatic NPR increase in the health sector. The plots in Figure 11 show that, compared with other nations, the United States has the highest science linkage in every sector. At the same time, in all sectors but health, TCTs are becoming faster. The slowing TCT for health might be explained by its marked increase in science linkage. It appears that the health sector is building more on research reported in scientific journals. Such research does not show up in the TCT value. Thus, the diminished dependence on patented prior art over a somewhat more mature base of patents tends to raise TCT values.

The EPTL and "All U.S. Patents" trajectories are similar. While EPTL technology incorporates optical imaging and other fairly advanced technologies, the bulk of EPTL is fairly conventional materials-handling technology, which is not very fast moving.

While similar to "All U.S. Patents" and EPTL in terms of TCT, the automotive sector is the least science-linked of all five sectors—even less than the average U.S. patent—and its linkage to science has changed little during this 15-year period. (This low science linkage might be explained by the maturity of the automotive technology sector, as evidenced by the relatively slow increase in the sector's rate of patenting activity and the industry's historical propensity toward incremental improvements, which are more likely to be developed as a result of applied research.)

The advanced materials sector is second only to health in its science linkage and has a fast TCT, second only to information technology. The health sector has a TCT value near that of the advanced materials sector, but with an NPR value much higher than any other sector. Finally, the very large information technology sector exhibits the fastest TCTs, but it is not as highly science linked as advanced materials or health.

The advanced materials sector is second only to health in its science linkage and has a fast TCT, second only to information technology.

How the Technology Positions of Individual Countries Differ

In every sector, Japanese patents have faster cycle times and are much less science linked than their U.S. counterparts.

The plots in Figure 11—developed using the same methodology as for Figure 10—break out the data for each sector and show the technology

European countries' trend lines track clearly with the Japanese trend line, not the U.S. trend line.

positions of key countries. Note that the magnitude of the scales in each plot are adjusted to suit each sector.

The plots in Figure 11 show that, in all sectors, Japanese patents tend to be much less science linked than their U.S. counterparts and have faster cycle times. In some cases, the trend line for the EU, Germany, and other countries is more like Japan's; in other cases, their trend lines are more like the United States'.

There is marked acceleration of the TCT values for Taiwan in the automotive and information technology sectors and for Korea in the information technology sector. Such acceleration indicates that these two countries are fast learners, emulating the Japanese industrial model with its emphasis on fast commercialization and far less dependence on basic or leading-edge science. A similar observation may be made concerning European patenting in the advanced materials sector, as these countries' trend lines track clearly with the Japanese trend line, not the U.S. trend line.

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